1 INTRODUCTION

URS Greiner Woodward Clyde (UGWC) and the Council for Information and Planning Alternatives (CIPA) were retained by Culebra's Project Impact, Inc. to conduct a hazard assessment and vulnerability analysis for the Island of Culebra.

1.1 Purpose

The purpose of this study is to identify major hazards that could affect the safety of residents and cause damages to homes, businesses, public facilities and infrastructure on the island. Individual hazard risk maps were prepared for the following natural hazards: flood, hurricane-strength winds, earthquake (includes tsunami), and landslides. A composite risk map was prepared for use in assessing future land use development. A structure inventory was prepared and incorporated into a vulnerability analysis to evaluate mitigation priorities.

1.2 Overview

In 1998, FEMA designated Culebra as its first Project Impact community in Puerto Rico. FEMA introduced Project Impact as a community planning initiative that challenges and supports communities to become more disaster resistant by undergoing a set of defined steps. These include building partnerships among local government, community groups, and volunteer organizations, assessing risks and developing an action plan for implementing mitigation measures.

This study supports Project Impact Culebra's goal of defining its risks and vulnerabilities in order to prepare for the inevitable disaster before it strikes, thus saving lives, property, and resources. The study provides a framework to unite constituencies in the community behind this goal.

Project Impact Culebra represents an emerging challenge to Culebra's rapidly changing community: to come together to define and prioritize competing mitigation needs to create a more disaster resistant and sustainable future.

2 PUBLIC INVOLVEMENT AND STRATEGIC VULNERABILITIES

Community involvement, an important part of this planning effort, involved two separate tasks: (1) interviews with key stakeholders throughout the community, and (2) several community workshops structured to bring the concerns and recommendations of the larger community into the study effort.

2.1 Definition of Strategic Vulnerabilities

To understand the context of development on the island, a series of interviews were held with individuals from various federal, municipal and state agencies. Below is a list of the agencies interviewed:

- Authority for Conservation and Development
- U.S. Fish and Wildlife Service
- Civil Defense
- Puerto Rico Electrical Power Authority (PREPA)
- Puerto Rico Aqueduct and Sewer Authority (PRASA), and
- Municipal Public Works Office and other municipal departments

The objective of these meetings was to develop an understanding of current development patterns and the community's exposure to natural disaster losses in view of its economy, environment, and infrastructure. Below is a discussion of different strategic sector vulnerabilities in Culebra.

2.1.1 Economic Sector

Traditional economic activities on Culebra focused on agriculture, including small-scale animal husbandry and fishing. Today, main employers include state and local government, a pharmaceutical company, and tourism. Tourism has become the most important economic sector on the island, displaying the highest and most stable growth rates, leaving the economy dependent on service activities.

Tourism is the most heavily affected economic sector when hurricanes strike the island. Because most of the tourist infrastructure is damaged after major hurricanes, the island cannot offer all the usual amenities. Therefore, there is a downturn in tourist activity, which results in a loss of revenue that adversely affects the entire economy of the island.

2.1.2 Natural Resource Sector

The island of Culebra's natural resources have become an increasingly important attraction for tourism. There is an active wildlife management program on Culebra managed by U.S. Fish and Wildlife Service. Theodore Roosevelt's administration established a national wildlife refuge on

Culebra in 1909. The refuge office administers about 1,480 acres of diverse lands including beaches, forests, lagoons and rocky precipices. Management efforts concentrate on education, protection of federal endangered species, maintaining areas in their natural conditions and avoiding disturbances by visitors.

Natural resource vulnerability to hazards includes damages from localized floods, high winds and landslides. Hurricanes have adversely affected shallow coral reefs and mangrove areas, a vital habitat for coastal wildlife. Mangroves provide nurseries for the abundance of marine life found offshore. Boundaries of the refuge are currently being surveyed to improve management activities. Of more important concern to refuge managers are the cumulative impacts of land development activities on refuge lands, lagoons and surrounding waters.

2.1.3 Planning and Development Sector

The Authority for the Conservation and Development is a municipality level organization that reviews and evaluates all construction and development projects proposed for the island, in coordination with the Puerto Rico Planning Board, and other state agencies. Meetings are held once a month, with representatives from the municipal government (Mayor), the Secretary of Department of Natural Resources (DRNA), PR Permits Office (ARPE), and five community members among others. They evaluate proposed development and make recommendations based on availability of infrastructure; impact on natural resources and other anticipated cumulative impacts. The Authority does not provide final permits. All development decisions are made at state level.

Development review procedures function well for large projects. However, illegal construction persists. The distinction between authorized and unauthorized construction is important. Development that occurs without appropriate building permits is more likely to be vulnerable to natural hazards.

2.1.4 Critical Facilities

Some of the critical facilities on the island include:

- **Energy:** The Island's primary power source is an underwater cable supply from Puerto Rico via the island of Vieques. Puerto Rico Electric Power Authority (PREPA) has a Hydro-Gas Plant (gas turbines), located in Dewey for the provision of power services in case of power interruption from the main island. Four diesel generators can produce up to 1,700 Kw. There are 300 Kw. of capacity available to serve future development if necessary. The plant is located in a coastal high hazard area.

  The power is distributed throughout the island via a linear distribution network. Cement poles are currently replacing wooden utility poles, however, installation of these poles need to be reviewed to ensure adequate depth and foundation support.

- **Water and Sanitation:** Puerto Rico Aqueduct and Sewer Authority (PRASA) supplies water from Puerto Rico through an underwater aqueduct. Installation of this system had a cost of over $7,400,000 dollars. The water distribution system is not island-wide and is limited to urbanized areas. PRASA also operates a desalinization plant for potable water distribution system. This plant is an emergency back-up facility but also provides water to areas currently not being served by the water distribution network.

There is currently no effective wastewater treatment facility for the island. Both residence and businesses are required to have septic tanks to hold wastewater. The municipality collects septic waste and deposits it in a holding tank and pond near Flamenco lagoon, on the northwest part of the island. The municipality has recently been awarded an EPA grant to construct a wastewater treatment plant. The project is a multi-agency effort. In addition to providing a critically needed public treatment facility, a secondary benefit of the proposed wastewater treatment plant is to restore the freshwater aquifer on Culebra.

Once the wastewater system is completed, there will be no major infrastructure constraints for future development. It is very important that the municipal government of Culebra takes a proactive position now to reduce future vulnerabilities.

- **Telecommunications:** The telecommunications infrastructure is entirely dependent on mainland facilities. Puerto Rico Telephone Company (PRTC) provides telecommunications service via microwave transmission which is received by an antenna on island. The island's telecommunication system is efficient, but is vulnerable to natural hazards, particularly hurricanes.

- **Ports Infrastructure:** The Puerto Rico Ports Authority administers a dock facility and airport. The port facility is vital for the transportation of passengers and especially cargo. The Culebra airport is a regional commuter airport served by commercial and private aircraft. Both these facilities are critical for the movement of people and products to and from Puerto Rico.

- **Transportation:** Transportation networks on the island are adequate for the current population. There are three main roads in Culebra that link residential areas to critical public facilities. Of particular concern to emergency response and recovery efforts is PR 250, which is the main access road between Dewey and Clark Community and the airport, which may be blocked by flooding during severe events.

2.2 Community Workshops

Community workshops provided the major public input to this study effort.

2.2.1 First Community Workshop

The first community meeting was held on March 8, 2000 to incorporate concerns of key community representatives. The workshop consisted of a brief background of this planning effort and was attended by various government representatives, local merchants, private organizations and concerned citizens. Emphasis was placed on residents' recent experiences with hurricanes, and the necessity to act immediately, to ensure preparedness for the next disaster event. It provided important feedback from people directly affected by disasters, their issues, concerns and recommendations about disaster recovery, natural hazards and reoccurring damages that have occurred in their municipality.

The major concerns identified by the community included:

- *Riverine and coastal flooding.* Many houses and structures are located along the Ensenada Honda shoreline. Some were affected by coastal flooding for the first time during Hurricane Hugo, but recent events had demonstrated that flooding is not limited to the coastal areas. Riverine flooding has occurred in Clark Community and La Romana Sector along guts where under normal conditions water barely flows. The storm drainage system may not be adequate in some areas and culverts and drainage ways are not functioning adequately especially along road PR 250, which is the main connector between Dewey and the rest of the community. This can be particularly critical due to the fact that state and municipal police, Civil Defense and community shelters are located in Dewey.

- *Landslides*. Landslides have affected Clark Community, La Romana and areas close to the airport, particularly during heavy rain events. Streets are damaged, footings of houses have been affected and access to some areas has been limited.

- *Inappropriate retrofitting and rebuilding*. Concrete, reinforced concrete, wood and a combination of these materials are normally used in the construction of homes and public buildings in Culebra. Municipal officials are aware that many residents are making a concerted effort to make their homes resistant to hurricane-strength winds, but many others are remodeling or rebuilding without following the proper construction standards. Families themselves execute the construction work without supervision or advise from professionals, and often without appropriate building permits. Construction techniques to provide continuous load paths are either not applied or applied inappropriately.

- *Education and a lack of hazard mitigation knowledge*. Community members pointed out that hazard mitigation should be part of everyday life for the people that live and work in a place so vulnerable to disasters. It needs to be part of the common language in Culebra. It was also mentioned that even those residents who have vacation homes on Culebra should be included in the public awareness effort, so their properties can be better protected when they leave for extended periods.

- *Inappropriate new construction and review process*. Rigorous procedures on approval and inspection of new construction, remodeling and retrofitting need to be applied consistently. This deficiency is most apparent following a disaster when great demands are placed upon the building permit review process. Residents voiced their concern on this particular issue because new home construction continues without appropriate controls, and not necessarily with disaster resistant techniques.

- *Technical and Economic Assistance*. Direct participation of local and state government needs to be harnessed in order to make residents aware of mitigation measures. Technical and financial assistance should be made available to residents and businesses to retrofit or make improvements to there properties.

2.2.2 Second Community Workshop

The second community meeting was held on August 3, 2000 to present the findings of the multi-hazard assessment and vulnerability analysis. The workshop consisted of a formal presentation in which individual hazard maps were explained to provide residents with a more thorough understanding of natural hazard risks on the island. Within the framework of sustainability, the project team presented proposed land use maps and an alternative-zoning map for the Island of Culebra. The workshop was well attended.

The Project Impact Committee, members of the Municipal Assembly and other concerned citizens were present and provided important feedback. Emphasis was placed on identifying risks, analyzing weaknesses or vulnerabilities and prioritizing mitigation actions. After the presentation, community members were asked to separate into three strategic planning groups to define mitigation objectives.

Among the major objectives brought out by the community were the following:

- Review and revise building codes and present low cost development alternatives that fit with construction budgets of island residents and development regulations.

- Expand the role of Project Impact to take a more proactive role in development processes, particularly housing and tourism.

- Create Community Action groups that will work with Project Impact in the retrofitting and strengthening of homes, debris removal, as well as protection of personal property. These groups would have the mitigation responsibilities and would also assist in an inventory of persons that need special assistance during early warning or evacuation.

- Develop a special program to make the marine industry and boating community aware of Project Impact's activities. The community expressed concern because there is a lot of coastal damage done by boats, which break from their mooring during storms.

- Develop technical assistance programs to increase awareness of mitigation and prevention measures. It was discussed that a long-term view should be taken by implementing mitigation awareness programs in schools and churches.

- Identify poorly constructed houses and provide assistance for retrofitting. Also identify those homes that are not economically viable for retrofitting and present occupants with an action plan for evacuation.

- Present hazard maps to the general public as part of a Project Impact educational program. Project Impact should create a permanent exhibition and use the maps as an educational tool for public viewing.

- Implement mitigation measures in existing shelters and minimize the expenditure of municipal resources by creating a network of family shelters.

- Identify areas of particular environmental concern and develop conservation or preservation plans for these areas, which are critical to the islands' tourism base.

- Work on educational campaigns that promote the concept of sustainability, addressing economic development, social issues and environmental concerns on an equal basis.

- That the findings of the multi-hazard risk assessment and vulnerability analysis be brought to the attention of Culebra's municipal assembly and to the PR Planning Board.

3 MULTI-HAZARD RISK ASSESSMENT

Four hazards were considered in the multi-hazard risk assessment: flooding, susceptibility to landslides, high winds from hurricanes, and, earthquakes. The following sections describe each of these hazards and the methodology used to assess the risk to the municipality. Following the discussion of the individual hazards, the methodology used for integrating these hazards into a composite risk map is explained.

3.1 Flood Hazard

In August 1978, the Government of Puerto Rico joined the National Flood Insurance Program (NFIP). The NFIP was created by an act of the U.S. Congress to make flood insurance available to property owners in communities that agree to enact and administer floodplain management regulations meeting program requirements. Initial Flood Insurance Rate Maps (FIRMs) of Puerto Rico were issued in August 1978; the most recent updates were published in 1999 (FEMA March 1999). The Government of Puerto Rico adopted NFIP-compliant floodplain management regulations under Planning Regulation 13. This regulation affects new and substantially improved construction in Special Flood Hazard Areas (SFHAs) identified as flood zones on the FIRMs.

The 100-year floodplain and the Coastal High Hazard Zone was used to delineate the flooding risk used in the multi-hazard risk assessment. This information was obtained from the FIRMs. Other than a few natural intermittent stream channels and constructed drainage ditches and culverts, there are no rivers or streams on Culebra due to the semi-arid conditions and volcanic rock formations. In coastal areas, shoreward of the major embayments, shallow lagoons, best exemplified by Laguna Flamenco, can be found. The lagoons, in addition to providing important wildlife habitat, also act as a filter, trapping fine sediment and pollutants, before surface runoff is discharged to off-shore waters.

In the coastal area of Culebra, buildings must be adequately elevated and protected from the effects of high-velocity storm surges (VE Zone). In VE Zones, new construction must be elevated on piling foundations and the lowest horizontal structural member of the lowest floor must be at or above the Base Flood Elevation (BFE). The BFE is defined as the elevation of the 100-year flood above ground level. In addition, the area below the building must be free of obstructions or enclosed by non-supporting, breakaway walls intended to collapse under wind and water loads without causing damage to the foundation or the elevated portion of the building. Within the 100-year floodplain, which are less likely to be affected by high velocity flow, the top of the lowest floor of the building must be at or above the BFE and the areas below the BFE can be enclosed with non-breakaway walls. However, the area below the BFE can only be used for parking, access, and storage. The Puerto Rico Planning Board and ARPE regulate Planning Regulation 13 (FEMA March 1999).

The most significant hazard on Culebra related to flooding is the high velocity storm surge zone, designated as Zone VE on the Flood Hazard Map. A recent study by the U.S. Army Corps of Engineers, FEMA, and Puerto Rico Defensa Civil, completed in May of 1997, provides more detailed information on storm surges associated with Category 1,3, and 5 hurricanes (Hurricane

Storm Tide Atlas for the Commonwealth of Puerto Rico). High velocity storm surges associated with hurricanes can cause severe damage to structures and represent a clear danger to residents living on the coast.

Flooding associated with major rainfall events (including the 100-year flood, defined as a storm with a one percent probability of occurring in any given year) has lesser significance than storm surges but is still an important consideration in natural hazards planning for the island. The 100-year floodplain is depicted on the Flood Hazard Map by Zone A (approximate boundary) and by Zone AE, where a detailed flood study has been conducted and a BFE has been determined. Two areas on the island should be specifically called out for attention. An area around the eastern end of the airport runway and extending along the shoreline to the town of Dewey is within the 100-year floodplain. This area has existing homes and businesses and there is some limited potential for future in-fill development. The floodplain surrounding Playa Flamenco also deserves special attention. Current land uses in the area include a resort hotel and public recreational facilities (state parkland). Special attention in the permit review process should be paid to any substantial renovation, expansion of existing uses or proposed new construction in this area.

3.1.1 Floodplain Management Recommendations

There are many steps that Culebra can take, with assistance from Puerto Rico Government (PRG) agencies and FEMA, to strengthen floodplain management, particularly in high-risk areas associated with coastal storm surges.

Nationwide, only one out of five homeowners in the floodplain have flood insurance. Culebra's Project Impact Committee could encourage greater participation in the National Flood Insurance Program (NFIP). Information on obtaining flood insurance and meeting floodplain requirements could be distributed to targeted high-risk areas.

Culebra can be better prepared to take advantage of future disasters by identifying and prioritizing hazard mitigation alternatives now. Identifying property owners and neighborhoods that have had repetitive flood damages and who are willing to participate in an acquisition program should be a priority. This would identify areas that are suitable for future acquisition or relocation. Taking this planning step prior to the next disaster would give your community a competitive advantage for receiving FEMA Hazard Mitigation Grant Program (HMGP) funds.

Having information at the local government level that is readily available and user friendly can greatly improve your floodplain management program. Floodplain boundaries can be overlaid onto aerial photography to provide an inexpensive way to illustrate the extent of the 100-year floodplain and VE Zone within Culebra.

The most effective way to reduce future flood-related damages is to discourage inappropriate development within the floodplain. The floodplain management regulations adopted by the Central Government of Puerto Rico are minimum requirements; the Municipality of Culebra may want to strengthen construction requirements or limit residential development in the floodplain.

Commercial development in the VE Zone could be limited to water dependant uses. Any revised regulations would have to be approved by the Planning Board.

Special attention is needed in the building permit review process for proposals to substantially repair, renovate or expand structures and for new construction permits in the VE Zone. For new development, property owners should be encouraged to cluster development, if feasible, at an elevation above 2.6 meters (7.8 feet), which is maximum predicted surge elevation for a Category 5 hurricane (1997 Hurricane Storm Atlas for the Commonwealth of Puerto Rico). This will not be possible for all future proposed coastal development; some shoreline parcels may fall entirely within the VE Zone. Consideration must be given to a property owners' development rights that cannot be entirely taken away by development restrictions.

Subdivision proposals should be carefully reviewed not to create small parcels that fall entirely within the VE of AE Zones. This would complicate building permit review when the buyer prepares to develop the newly created parcel.

3.2 Landslide Hazard

Landslides are an ongoing geologic process in Puerto Rico. Landslides can vary in size from a few cubic yards of soil or rock to entire hillsides hundreds of feet long. Although some naturally occurring landslides can have a disastrous effect in Puerto Rico, they occur relatively infrequently. The geologic process that produces such landslides proceeds slowly with respect to historic time. Most of the economically significant landslides that occur in Puerto Rico are the result of failures of man-made, cut and fill slopes following major rainfall events.

Puerto Rico's steep topography and shallow, fine-grained soils over bedrock make it highly susceptible to landslides. During Hurricane Georges, widespread intense rainfall in the mountainous regions of the main island resulted in numerous landslides that blocked and undermined roads, and, in some instances destroyed entire homes. The geologic formations on Culebra, however, do not present a significant landslide risk. The Project Team, during reconnaissance fieldwork on Culebra did evaluate several small landslide events that followed Hurricane Georges. There is little historical evidence of major landslide activity on any of the major geologic rock formations present on the island.

A map showing landslides and areas of susceptibility to landslides in Puerto Rico, developed by Watson H. Monroe in 1979 (1:240,000), was used to identify broad zones of susceptibility. The Island of Culebra was identified as being in an area of low susceptibility to landslides. This becomes understandable when evaluating the geologic rock formations present on the island. The geology is volcanic in origin and the major diorite and andesite formations are not deeply weathered or fractured. This is not to say that landslides are not a hazard on the Island of Culebra because other factors need to be considered.

Factors contributing to landslides include the type of geologic bedrock, excessively steep cut and fill slopes along roads and for hillside development, and inadequate surface and subsurface drainage. The risk categories shown on the Landslide Susceptibility Map are derived primarily from slope information. As percent slope increases, the potential for landslides also increases. Properly designed, constructed, and maintained slopes and drainage facilities can often overcome these factors that contribute to landslides. However, the cost of constructing stable slopes becomes significantly higher when the natural slopes are steeper than about 35 percent (19.3° or 2.9H:1V). These three different measures of slope are respectively defined as percent slope, degree of slope and slope ratio or horizontal distance over vertical rise in distance.

A special category of landslides is referred to as "debris flows." Debris flows are rapid mass movements of a slurry of soil, rock, water, and vegetation. Debris flows occur in steep-sided drainages that extend up hillsides. There is typically no warning of the impending failure. Debris flows are initiated when intense rainfall causes the sides of the drainage to fail by landslides. The saturated material loses structure upon failure, and takes on the consistency of mud. The mud flows down the flow line of the drainage at a velocity that depends on the consistency of the mud (and incorporated rocks and vegetation) and the steepness of the flow line. Velocities can exceed 30 miles per hour. Debris flows can cause significant structural damage and/or personal injury both within the drainage on the hillside and on the flatter areas at the bottom of the hillside. The presence of past debris flow deposits is an indicator that debris flows will re-occur in the same drainage during future heavy rain events.

3.2.1 Landslide Recommendations

The following recommendations will reduce the potential for cut and fill slope failures during periods of heavy rain or earthquakes:

- Avoid development, where possible, of any public facilities in areas having natural slopes steeper than 50 percent. Construction of residences and roads on slopes greater than 50 percent is subject to a high hazard risk for landslides and should be discouraged in the subdivision and site plan review process. The Municipality of Culebra should note accept private roads for public maintenance in areas of slopes greater than 50 percent.

- The risk of cut and fill slope instability becomes progressively higher as the inclination of the natural ground increases from 35 percent to 50 percent. The risk of cut and fill slope failure in this range of natural slope can be considered as moderate.

- Avoid development within and directly below steep-sided drainages that extend up hillsides. Such areas are susceptible to debris flows.

- Proper engineering should be required for the design for all major cut and fill slopes, whether the proposed development is publicly or privately developed.

- Jibson (1986) recommended the following hazard mitigation measures that should be considered by the municipality: use flatter slopes for roadcuts; require adequate sewage disposal systems for new home construction so that hillsides will not become saturated and destabilized; use plastic piping to direct sewage disposal to the sides of existing homes, rather than down slope of the home; install subsurface storm drains for new developments; and, channel runoff safely away from existing or proposed developments on steep slopes.

3.3 High Wind Hazard

The National Weather Service (NWS) reported wind speeds from Hurricane Georges from 109 mph with gusts to 133 mph as it crossed the island of Puerto Rico. Based upon recorded data and observations, the wind speeds experienced in Puerto Rico during Hurricane Georges did not exceed the basic design wind speed of 110 mph found in Planning Regulation 7 (FEMA, March 1999). Thus, the wind speeds that occurred were not strong enough to test the engineering design storm described in the regulations.

Even though Hurricane Georges did not exceed the design storm, a large number of residential buildings in Puerto Rico experienced structural damage from Hurricane Georges. The FEMA Building Performance Assessment Team (BPAT) concluded that although all damages caused by Hurricane Geroges could not have been prevented, a significant amount of damages could have been avoided if more buildings had been constructed to the existing Planning Regulation 7 (building code in effect at that time).

The damages were most often attributed to a lack of a continuous load path from the roof structure to the foundation (FEMA, March 1999). If a building was designed and built with a continuous load path, then the forces and loads acting on any portion of the building will be transferred to the foundation of the building. The transfer occurs through building structural members (columns, rafters, and beams) and the manner in which they are connected.

Following Hurricane Georges, the Government of Puerto Rico adopted the 1997 Uniform Building Code (UBC). The 1997 UBC incorporates extensive wind engineering research that has occurred since Regulation 7 was amended in 1987. The newly adopted code references updated national standards for concrete and steel construction. More importantly, the 1997 UBC has specified design standards that include the use of a refined wind load model (ASCE 7-95) for determining design wind loads for new buildings. These modifications address most of the wind provision deficiencies that existed under Planning Regulation 7.

The Project Team modified the ASCE 7-95 wind model for the development of the High Wind Hazard Map. The high wind hazard model is a GIS based generalization of these procedures at a scale felt suitable for input to the land use planning process. Results of the analysis are intended to indicate the relative wind hazard on a larger scale than originally intended and its use should not be substituted for the detailed building specific wind hazard loaded assessment developed by the ASCE. The procedures developed by the ASCE for the calculation of the wind loading require information on basic wind speeds, building type and height, exposure, wind gusts and topography. For this GIS based planning level analysis only the topographic effects of wind loading were considered, all other factors influencing wind speed-up are assumed to be constant.

3.3.1 High Wind Recommendations

Following Hurricane Georges, recommendations related to minimizing the adverse effects of hurricane-strength winds focus primarily on Puerto Rico's Regulations and Permitting Administration (Administracion de Regalmentos y Permisos or ARPE). ARPE has taken several important steps following Hurricane Georges to increase public safety and reduce property damage from natural hazards. At ARPE's request, the International Conference of Building Officials (ICBO) conducted and completed an external review of ARPE in January 1999. The external review assessed how ARPE administers and enforces planning regulations related to building design and construction. The review resulted in recommendations in the area of policy, procedures, practices, training and education.

ARPE faces difficult challenges ahead to implement many of the ICBO recommendations. The BPAT and ICBO reviews identified unregulated and illegal construction throughout much of Puerto Rico. Loopholes in the regulations and a general lack of enforcement allows for unregulated construction of residential buildings.

Culebra's Project Impact Committee may want to encourage the Municipality government to try to strengthen ARPE's oversight role for residential and commercial construction on the island. Given ARPE's historical lack of attention in Culebra to building permit review and absence of construction inspections, attempts to strengthen ARPE involvement may prove difficult to attain.

Other general recommendations include:

- Encourage architects, engineers, and contractors working in the municipality to be knowledgeable about the newly adopted building code and provisions for making structures more resistant to high wind damages.

- Continue on-going training seminars regarding retrofit opportunities and improving current construction techniques for making structures more disaster resistant.

- Since Hurricane Marilyn, FEMA has developed a wide-range of public awareness materials, brochures, and construction manuals for high-wind strengthening. Culebra's Project Impact Committee may want to review these materials and customize them to address standard construction practices found on Culebra.

- Encourage continued involvement of the College of Engineers as a Project Impact Partner in training programs and developing recommendations concerning disaster-resistant construction techniques.

- Encourage the Authority of Conservation and Development to take a more proactive role in the development review process. Pursue a Memorandum of Agreement (MOA) with ARPE to more closely monitor construction activity on the island and provide the means for local enforcement by the issuance of penalties.

3.4 Earthquake Hazard

Along with much of the Caribbean, Puerto Rico is subject to significant earthquake and tsunami risk. The written history of earthquake damage in Puerto Rico dates back to 1867 when the first earthquake was documented, with an estimated magnitude of 7.3 on the Richter scale occurring off southeast Puerto Rico. The 1867 earthquake had an associated tsunami that struck the U.S. Virgin Islands but did not affect the islands of Vieques or Culebra. In 1918, Puerto Rico was struck by a massive 7.5 magnitude earthquake. The epicenter was located approximately 9 miles off the northwest coast. The ensuring tsunami had wave heights approaching 19 feet and caused major damage. Reportedly, 116 people were killed, 40 as a direct result of the tsunami (FEMA March 1999). No damage was reported from Culebra.

Culebra and adjacent islands are underlain by volcanic and intrusive rocks of probable Upper Cretaceous age. Andesite bedrock underlies most of the island and many seacliff exposures exhibit pillow larva that is characteristic of lava that has cooled under the sea. Associated with the andesite lava is volcanic breccia, composed of small pyroclastic rock fragments. An area of tuff, compacted volcanic ash and fine sediment, is located on the northeast portion of the island. The andesite tuff is characterized by prominent layering with beds ranging from a few inches to many feet thick. The tuff and underlying andesite lava have been intruded by diorite in north central Culebra. The diorite weathers to rounded boulders several feet in diameter, which cover much of the steep north central slope of Culebra. The geologic description is abstracted from an investigation conducted by T. W. Donnely in 1959.

Culebra is located within Tsunami Hazard Zone 3 that indicates a potential exists for a tsunami in the range of 15 to 30 feet. (USGS Open File Report 85-533). The hazard risk associated with tsunamis was incorporated into the multi-hazard risk assessment by assigning a greater relative risk to the elevation contour bounded by sea level to 5 meters and a lesser relative risk to the contour interval from 5 to 10 meters. No significant submarine faults are known in the immediate vicinity of Culebra, although a general swath of seismic activity has been detected in an area north of the US and British Virgin Islands that can not be tied to any currently known submarine fault systems. Seismic stations that are proposed for Culebra and on the Virgin Islands may be able, over the long term, to provide more detailed seismic risk data, on this questionable area of seismic activity.

The available geologic information on Culebra does not allow the Project Team to make planning level distinctions for the multi-hazard risk assessment. The diorite and andesite rock formations are both hard bedrock types with little apparent weathering and fracturing. Local geologic experts[1] were not overly concerned about the rock formations on Culebra amplifying ground acceleration movements during an earthquake. The recent alluvium of sands and finer sediments are shallow depositions over hard bedrock. Hence, liquefaction during seismic events is not a major concern. The Hydrologic Map of Puerto Rico and Adjacent Islands (R.P. Briggs and J.P. Akers, 1965) does show several inferred fault lines trending from the northwest to the southeast on the island. There is no information to indicate that these inferred fault lines are active. Additional site-specific investigation would be required to determine if there are any indicators of recent geologic activity along the inferred fault lines.

Christine van Hildebrandt did express a concern about the small number of structures in Dewey found along the Laguna Lobina, a constructed waterway that provides access to the Ensenada

[1] The planning implications of the seismic risk related to the geologic formations on Culebra and the surrounding submarine fault systems were discussed with Christine van Hildebrandt, seismologist with the University of Mayaquez. Additional discussions on construction concerns related to the bedrock geology present on the island were held with Ramon Alonso Harris, geologist with the Puerto Rico Department of Natural Resources.

Honda. Some of these structures, mostly commercial land uses, were constructed on fill land that may become unstable during a seismic event.

3.4.1 Seismic Risk Recommendations

The most important hazard mitigation recommendation for the seismic risk identified on the Island of Culebra is to design and construct new buildings in accordance with the latest building codes. The American Society of Civil Engineers Standard 7-95 (ASCE 7-95), Minimum Design Loads for Buildings and Other Structures, as well as the National Earthquake Hazards Reduction Program (NEHRP 1997) include provisions that require all structures in Puerto Rico, including single family homes, to be seismic resistant. These documents have strict standards for incorporating seismic considerations into building construction. The 1997 Uniform Building Code (UBC), adopted in Puerto Rico in December 1998, is compliant with both the 1997 NEHRP and the seismic provisions of ASCE 7-95 (FEMA March 1999).

The Island of Culebra, as well as the mainland of Puerto Rico, is subject to Seismic Risk Zone 4, indicating high seismic risk. Given the volcanic hard rock formations present on Culebra, and the lack of major structural fault systems in the vicinity of Culebra, the Zone 4 construction standards may be considered conservative.

Retrofitting existing buildings is difficult and expensive but the Project Impact Committee may want to consider seismic retrofits for critical public facilities such as medical facilities, schools and shelters.

3.5 Composite Risk Map

One of the strengths of utilizing a GIS approach for a multi-hazard risk assessment is the ability to combine the individual risks and develop a composite risk map for the region. A vulnerability index was prepared that considers the intensity of potential damages and the reoccurrence interval for each hazard type. The vulnerability index permits a comparison between very different hazards by modifying the qualitative risk rating established for each individual hazard.

The reoccurrence interval was determined for high winds, floods and landslides by evaluating the occurrence of threshold events that have led to substantial damages since 1989. Tsunami and earthquakes are not well documented as the most recent major earthquake in Puerto Rico occurred in 1918. The intensity values determined for high winds, flood and landslide reflect information from the most recent five disaster declarations (Hurricane Georges, Hortense, and Marilyn, the Three Kings Flood, and Hurricane Hugo). Based upon the damage assessment described in the Interagency Hazard Mitigation Reports and data compiled by FEMA on disaster costs, the percent damage by hazard type was estimated for each disaster. The intensity factor was devised from actual damage estimates by hazard type aggregated over the last five declared disasters.

The vulnerability index is derived by multiplying the reoccurrence interval by the intensity factor. The numerical values assigned for low, moderate, high and severe risks were then multiplied by the vulnerability index for that specific hazard type. The weighted hazard indexes for flood, high wind, landslide susceptibility and seismic hazards were then added to create the Composite Risk Map. The composite risk was classified into low, moderate high and severe risk categories. As an overall policy goal for local government, development should be encouraged in areas classified as having a low composite risk and discouraged in areas of higher risk categories.

3.6 Proposed Land Use Map

The summary planning recommendations of the Project Team are reflected in the Proposed Land Use Map. This map was prepared by evaluating the Composite Risk Map and determining broad areas in the municipality where development should be restricted because of the presence of natural hazards and areas where development should be encouraged because of the lower risks present. Many other factors were taken into consideration in defining the proposed land uses. Transportation corridors, existing land use and public infrastructure were considered in the analysis.

Five major planning recommendations are illustrated on the Proposed Land Use Map:

3.6.1 Future Growth Areas

Five future growth areas surrounding Dewey and Ensenada Honda are depicted. These areas are recommended for higher density residential development. These areas are located in areas of lower hazard risk and are proximate to existing public infrastructure.

Of particular concern is an existing land use trend in urbanized areas that has serious implications for long-term sustainability. As residential areas have built out over the past few decades, new residential development has occurred as an extension of the linear road pattern into areas of higher hazard risk. A more sustainable land use pattern would be to develop new residential streets, in low risk areas, that are closer to public infrastructure. The five growth areas depicted on the Proposed Land Use Map meet these criteria and provide enough land area in lower risk areas to meet future residential demand.

3.6.2 Development Restrictions

Development should be discouraged in the areas of high hazard risk depicted on the Proposed Land Use Plan. These areas include high and severe risk from hurricane-strength winds and areas susceptible to landslides. Zoning and subdivision regulations provide the best tool for Culebra to create a more sustainable and disaster resistant future. Strict application of the floodplain ordinance will be essential to minimizing future damages in the 100-year floodplain and the VE Storm Surge Zone.

3.6.3 Potential Hazard Mitigation Acquisition Zone

The area depicted on the Proposed Land Use Plan represents an area of high hazard risk from storm surges, flooding and tsunami. The area includes currently developed shoreline homes along PR 250 from Dewey to the airport. These areas have been adversely affected by past storm events. The Project Team recommends identifying this area as a potential hazard mitigation acquisition project, should FEMA HMGP funds become available in the future. Having a potential acquisition project pre-packaged would place Culebra in a competitive position for receiving HMGP funding.

3.6.4 Recreational and Environmentally Sensitive Areas

Eight coastal areas are identified as areas deserving protection from inappropriate development. These areas are subject to high hazard risk from flooding, storm surge and tsunami. In addition, several of these areas represent valuable tourist destinations and are critical to the overall tourism economy of the island. Finally, these areas are extremely environmentally sensitive areas and represent critical wildlife habitat for diverse wildlife including several federally endangered species. Development should be discouraged through zoning, subdivision, acquisition, purchase of development easements, or other land use planning tools.

3.6.5 Low-Density Rural Area.

The area outside of the urbanized and future growth areas that is depicted in light yellow should be reserved for future low-density residential development without provision of public sewer. Loopholes that currently exist in Puerto Rico’s subdivision regulations and review procedures that allow property owners to subdivide rural lands into smaller parcels (one to five acre lots) need to be eliminated. In the rural eastern portion of the island, property owners are currently using this loophole to create numerous small acre lots, primarily for second-home development. If allowed to continue, it will lead to an inappropriate land use pattern in the rural zone.

3.7 Review of the Territorial Plan and Proposed Zoning

The project team recently reviewed a digital copy of the proposed zoning map for the municipality of Culebra, part of phase four of the territorial plan (final plan)[2] The Project Team has reviewed the proposed zoning by overlaying the zoning map on the Proposed Land Use Map described in the previous section.

Our overall finding regarding the proposed Territorial Plan is that its implementation would lead to an unsustainable future for the municipality. The Project Team recommends that the municipal assembly should not adopt the proposed zoning, in its current form. Its adoption would lead to a low-density sprawl development throughout the island that is oriented towards second home construction. Furthermore, it does not provide adequate areas for higher density development for Culebrenses in the more urbanized zone where infrastructure is currently available.

Dramatically increasing the number of expensive second homes will increase the property tax base of the municipality. However, increased municipal costs can also be expected as a result of development. This type of development would lead to soil erosion and degrade the value of the island's natural resource base, which is an important attraction for tourism. The standard one lot per five acres allowed in the RO5-C zoning district will require an extensive road and utility network and promote new home construction in areas of high hazard risk.

The Project Team's alternative zoning map builds upon the multi-hazard risk assessment conducted for Culebra. (See maps in Appendix 3) The alternative-zoning map provides a compromise that allows RO5-C zoning in rural portions of the island, but retains the RO25-C zoning in areas of high composite hazard risk and in areas where preservation of the natural resource amenities is critical to maintaining the commercial tourism base of the island. The major recommendations included in the alternative zoning include:

- Retain RO25-C zoning classification for high hazard areas. This zoning is legally justified because of the multi-hazard risk assessment methodology and because extensive areas of lower hazard areas are shown with zoning densities between 1 dwelling unit per acre to 5 dwelling units per acre.

- If property owners have large tracts of land with both RO25-C and RO5-C lands, they should have the ability to transfer development rights from the high hazard zone to the RO5-C portion of the tract.

- Portions of RO1-C zoned lands on the western side of the island have been modified to better relate to hazard risk and two RO1-C zoned lands near Zoni Beach are recommended for reduced zoning densities (either RO5-C or RO25-C).

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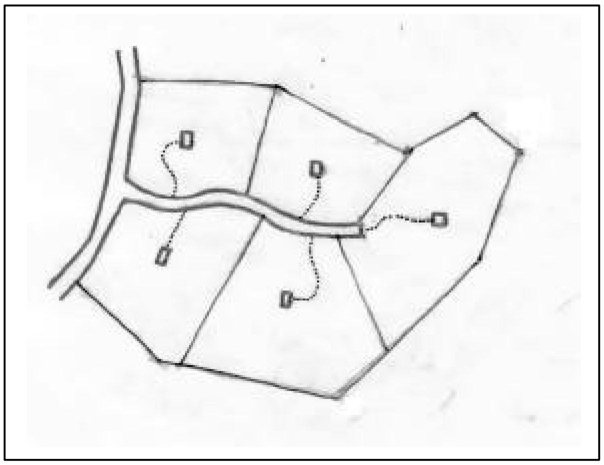
[2] On July 27, 2000, the Project Team met with Mr.Guillermo Godreau, consultant to the Municipality of Culebra for phase four of the Territorial Plan (final plan). Mr. Godreau provided the Project Team with a digital copy of the proposed zoning and explained the current status of the planning process.

- In the RO5-C district property owners would have the right to subdivide property into minimum 5-acre lots, however, the cluster development provision should be strengthened to specifically include all residential uses not just vacation and recreational uses. The cluster provision would not have a minimum lot-size requirement but would only allow one lot greater two acres. It would also include a density incentive, perhaps allowing property owners to achieve a density bonus incentive of up to l.3 times the number of dwelling units allowed under the 1 dwelling unit per 5 acre requirement. For example, a 25 acre tract, under standard subdivision would yield 5 lots; under a cluster arrangement you be able to get 6 lots. Likewise, a 100-tract would yield 26 clustered lots, rather than the 20 under conventional subdivision.



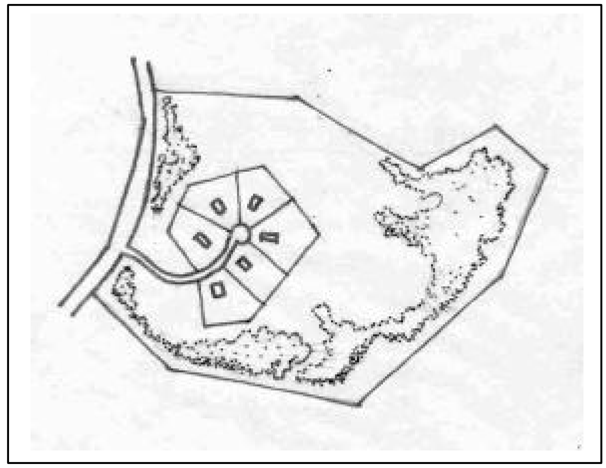


Figure 3.1. Existing five-Acre Subdivision vs.Cluster Development Option

- Zoning conditions for permitting paradores, hotels and inns in the RO5-C zone should be strengthened. Inns and small bed and breakfast establishments (B&B's) should not be a permitted use in the RO5-C but should also fall under the same special exception requirements as listed for paradores and hotels. There should be restrictions on the number of rooms that should be allowed for all tourist accommodations outside of the urbanized zoning districts.

- Retain RO25-C as a Buffer for preservation of high-value tourism areas and natural resource protection. These areas are generally located in high-hazard zones, are environmentally sensitive, and are critical for maintaining the tourism-based economy. The environmentally sensitive areas include coral reefs, coastal embayments, and adequate buffers surrounding these features.

- The zoning map proposed in the Territorial Plan does not show adequate enough land area for future development for the residents of Culebra. A larger future growth area should be shown outside of the existing urbanized area. By transitioning immediately to the RO5-C zone, there will not be adequate and affordable lands that allow higher residential densities.

The URS/CIPA proposed zoning expands the urban zone to include adjacent undeveloped lands with low composite hazard risk. These lands should be reserved for higher densities and should not be developed into five-acre lots, precluding future higher density development adjacent to existing infrastructure.

These alternative zoning recommendations would result in a more sustainable future for Culebra, provide more opportunities for Culebrenses to build homes in the urban growth areas proposed, and reduce the environmental degradation and loss of tourism potential associated with zoning proposed as part of Territorial Plan.

The Project Team encourages the Project Impact Committee to clearly voice these concerns to the municipal assembly who must adopt the final plan following a public hearing.

4 VULNERABILITY ANALYSIS

The vulnerability analysis plays a vital role in assisting Project Impact Culebra's efforts in preparing for natural disasters and mitigating their effects. A structure inventory provides the tool for prioritizing mitigation actions, supporting day-to-day operations of stakeholders as well as applications for disaster preparation, response, and recovery activities. The inventory consisted of four phases:

(1) Preparation of a detailed base map,
(2) Development of a rapid investigation sheet and methodology;
(3) Development of a database application for data entry; and
(4) Vulnerability analysis

4.1 Field Survey methodology

It was determined that a rapid visual investigation should be conducted as a prelude to more detailed site-specific structural assessment. To facilitate this process, a series of GIS base maps were created from high-resolution aerial photography. The entire island was divided into fifty-three (53) blocks or working areas in which an identification number was to given to individual structures within a particular working area. An inventory sheet was also developed to allow field inspectors[3] to capture important information in a consistent manner.

The project team developed a simple database application used to input tabular data. This application, through the use of simple data entry screens, allowed greater quality control during data entry procedures. Once data was entered into the system, the project team conducted standard quality assurance and control routines to verify data elements to existing digital GIS Mapbase.

3 Field inspection were conducted by the Puerto Rico College of Engineers and Surveyors (CIAPR) and the Council for Information and Planning Alternatives, Inc. (CIPA)

PROJECT IMPACT CULEBRA
Structure Inventory

STRUCTURE ID	_______ – _______ Block No.
Inspector:	Date:

Address: | **Picture ID:**

Building Type: ☐ Single-Family ☐ Commercial ☐ Mixed-use (describe):
☐ Multi-Family ☐ Public

Height: ☐ 1 story ☐ 3 stories ☐ 2 stories ☐ More stories ( )

Age: ☐ Less than 1 year ☐ 6 - 10 years ☐ Over 20 years ( ) ☐ 1 - 5 years ☐ 11 - 20 years

Size: ☐ Less than 600 sf ☐ 1500 - 2000 sf ☐ 600 - 1000 sf ☐ Other ( ) ☐ 1000 - 1500 sf

Quality of construction: ☐ poor ☐ low ☐ fair ☐ good ☐ very good

Building construction: ☐ Slab on grade ☐ Raised first floor [height:____]

Substructure: ☐ Concrete footing ☐ Wood piling ☐ Concrete piling ☐ Block piling

Floor:

1st	2nd	3rd
☐ wood	☐ wood	☐ wood
☐ concrete	☐ concrete	☐ concrete

Walls:

1st	2nd	3rd
☐ wood	☐ wood	☐ wood
☐ concrete	☐ concrete	☐ concrete

Roof Framing: ☐ Concrete ☐ Wood/panel ☐ Metal on wood

Roof Cover: ☐ Concrete ☐ Wood/panel ☐ Metal on wood ☐ Built-up

Roof Pitch: ☐ Flat ☐ Steep ☐ Medium

HAZARD IDENTIFICATION

Flood

Coastal ☐ N/A
Height above water line: ☐ 1 foot ☐ 2-5 ft ☐ 5-10 ft ☐ 10-20ft
Distance from shore: ☐ < 10 ☐ > 20 ☐ > 50 ☐ > 100 ☐ > 150

Riverine ☐ N/A
Hazard from gut: ☐ Yes ☐ No Height form gut: ☐ < 2 ☐ > 5 ☐ > 10
Distance from gut: ☐ < 5 ☐ > 10 ☐ > 15 ☐ > 20

Wind

Window materials: ☐ glass ☐ metal ☐ wood Shutters: ☐ Yes ☐ No
Window Sizes: ☐ 3x5 ☐ 5x5 ☐ 6x5 ☐ > 7x5
Roof Height: ☐ Less than 30 ft ☐ Over 30'
Roof overhang ☐ No ☐ 0 to 18"' ☐ Over 18"
Will topography have an effect on the wind ? ☐ Yes ☐ No
Roof mounted equipment: ☐ Yes ☐ No ______________________
Previous damages: ☐ Yes ☐ No ______________________
____

For Public, Critical or Large Commercial Structures

Use: ☐ police ☐ fire ☐ school ☐ manufacturing ☐ other ____________
Doors: ☐ small ☐ large Doors type: ☐ wood ☐ metal ☐ glass
Shelter: ☐ Yes ☐ No Utilities vulnerable: ☐ Yes ☐ No

In Your opinion: Does it require more study?: ☐ Yes ☐ No
Comments: ______________________
____

Figure 4.1. Project Impact Inventory Sheet

4.2 Vulnerability Ranking

During the first community workshop, PIC Committee members placed emphasis on reinforcing, protecting and retrofitting residences. Homeowners feel this to be the first priority that PIC should take into consideration when implementing a mitigation action plan. Within the broad category of residences, single-family units, the most common, were given the highest priority. A series of structure characteristics were analyzed to determine their vulnerability to natural hazards.[4] The objective of this analysis is to rank the vulnerability of structures in order to implement hazard mitigation measures such as acquisition of vulnerable homes in the storm surge zone or retrofitting existing homes for greater resistance to high wind damages. Subsequent to the vulnerability analysis, more detailed structural assessments may be necessary.

The structure inventory counted one thousand one hundred and eighty-six (1186) structures island-wide, including single and multi-family homes, public, and commercial and other mixed-use structures. Of this total, nine hundred ninety-five (995) structures are private homes and counted for 84.0% of all structures inventoried. Within this grouping, nine hundred forty-five (945) were single family and only fifty (50) were identified as multi-family structures. Mixed-use structures totaled fifty-eight (58) or 4.9%, while commercial buildings totaled fifty-nine (59) and comprised 5.0% of all structures identified. Those buildings identified as being designated for public use, including schools, police and fire stations and infrastructure facilities, totaled forty-two (42) or 3.5% of the Culebra's building stock.[5]

Building Type	#	%
Residential Structures	995	83.9
Single Family	945	79.7
Multi-Family	50	4.2
Mixed Use	58	4.9
Commercial	59	5.0
Public	42	3.5
Others	16	1.3
Not specified	16	1.3
Total of Structures	1186	100.0

Table 4.1 Culebra Building Types

[4] Structure characteristics used in the vulnerability analysis are defined in Appendix 1 "Database Tables and Attributes". This also highlights the fields that were used to determine structure vulnerability for each individual risk.

[5] Those structures whose use was not categorized numbered 32 and represented 2.6% of all structures on the island.

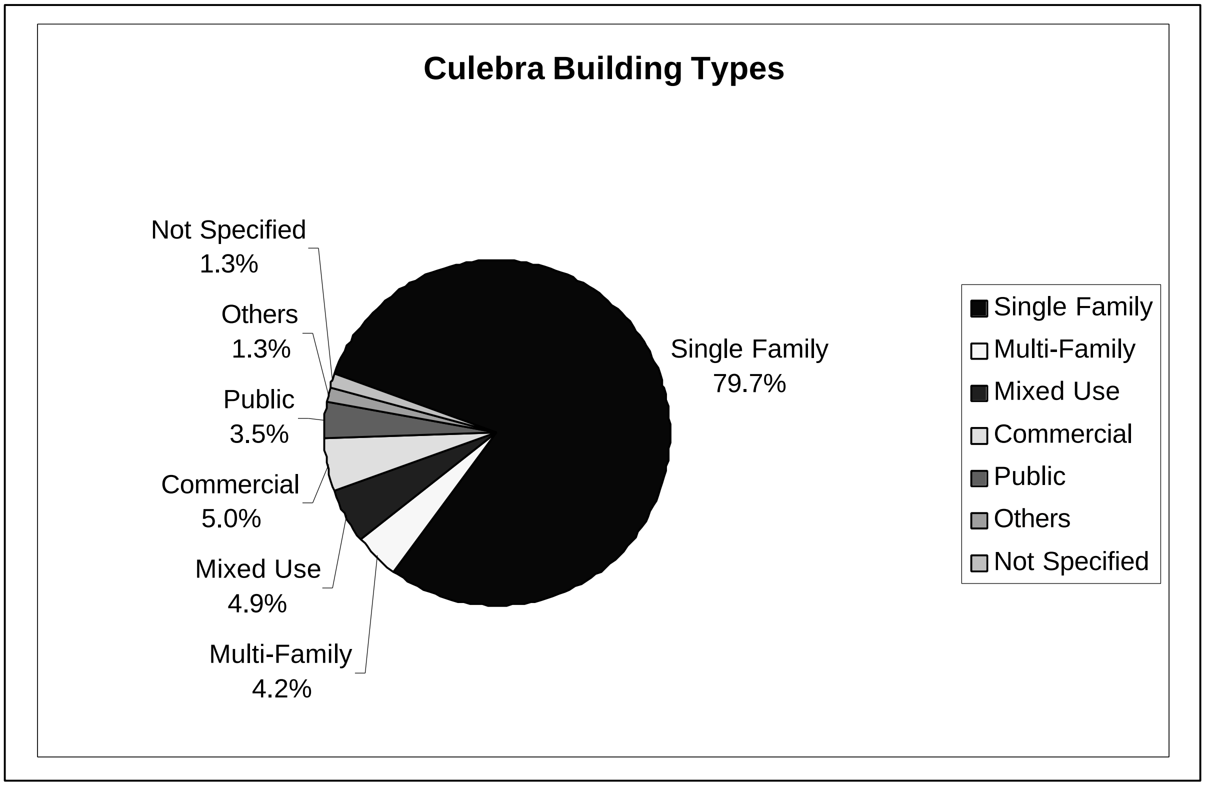


Figure 4.2 Culebra Building Types

Of all structures, residences, public facilities and commercial structures, identified in the survey, 71.3% were one-story buildings, 24.6% were two-story buildings and 2.5 % of the structures have three or more stories. Size of buildings also varied, from homes having less than 600 square feet to vacation homes that have greater than 3,000 sq. ft. A total of three hundred sixty-eight (368) units or 31.2% have less than 600 sq. ft. while four hundred twenty-seven (427) structures or (36.2%) are between 600 and 1000 sq. ft. One hundred seventy-six (176) structures or 14.9% were estimated to be between 1000 and 1500 sq. ft. and a total of two hundred fifteen (215) were estimated to be larger than 1500 sq. ft.

General Structure Characteristics		
Height of Structure		
#Stories	***#***	***%***
1	842	71.3
2	290	24.6
3	29	2.5
Not specified	25	2.1
Total	1186	100.4
Age of Structure		
Years	#	%
< 1	117	10.8
1 - 5	254	23.5
6 - 10	324	30.0
11 - 20	224	20.7
Over 20	139	12.9
Not specified	128	11.8
Total	1186	109.7
Size (sf) of Structure		
Size (sf)	#	%
< 600	368	31.2
600-1000	427	36.2
1000-1500	176	14.9
1500-2000	112	9.5
> 2000	49	4.1
Not specified	54	4.6
Total	1186	100.4

Table 4.2 General Structure Characteristics in Culebra

4.3 Quality of Construction

Quality of construction is an important factor for determining levels of intervention, mitigation and retrofitting. The quality of construction index was determined by examining construction techniques, selection and combination of building materials from the field survey database.[6]

Out of nine hundred forty-five (945) structures that were identified as being single-family dwellings, a total of eighty-nine (89) houses or 9.4% were considered to be of poor construction. Additionally, ninety-two (92) or 9.7% of the structures were evaluated as having a low quality of

[6] This quality of construction index should be considered subjective, as engineers or architects conducting the survey did so from the outside of the structure and did not conduct a detailed assessment of structure integrity.

construction and two hundred and fifty-three (253) or 26.8% were identified as being in fair condition. Three hundred forty-one (341) or 36.1% of the homes were identified as exhibiting good construction standards and one hundred and twenty-five (125) were considered to have very good construction (13.2 %).[7].

Out of fifty (50) multiple family dwellings identified, thirty-nine (39) or 78% were found to have good and very good construction techniques, nine (9) or 18% were categorized as having fair construction and only 11 structures (22%) were considered as having poor or low quality of construction. For mixed-use structures, 66% of the structures showed good or very good construction. Only 7.6% of this group was evaluated as having poor or low construction. On the other hand, 53% of commercial structures are recognized as good and very good, while 42 % are included to be of poor, low and fair construction.

Quality of Construction (Single Family Homes)	#	%
Poor	89	9.4
Low	92	9.7
Fair	253	26.8
Good	341	36.1
Very good	125	13.2
Not especified	45	4.8
Total	945	100.0

Table 4.3 Quality of Construction of Single Family Homes

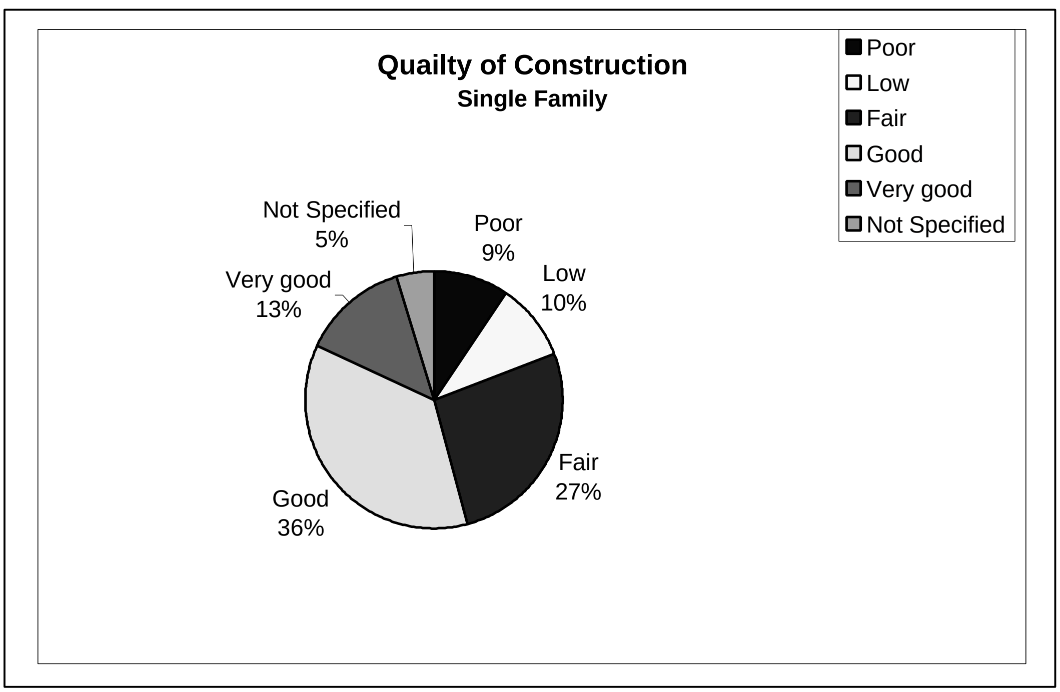


Figure 4.3 Quality of Construction of Single Family Homes

[7] A total of 45 structures were not evaluated or omitted by field surveyors, representing (5%) of all structures

4.4 Vulnerability to Wind Hazard

Many different factors were used to evaluate structures to a high wind hazard. Data elements such as the number of stories, materials and type of construction for slabs, walls, floors, roof framing and roof cover were identified as important to evaluate vulnerability to this type of risk. Other factors included roof pitch, window material and size. Wooden roof overhangs and structure heights were given added weight to the ranking methodology.

For all single-family units, a total of three hundred and seventy-two (372) structures or 39.4% were considered as having low vulnerability to hurricane wind effects. A total of ninety-seven (97) houses or 10.3% were classified as highly vulnerable, while half of the single-family dwellings (476 houses) fell into the moderate risk category.

Wind Vulnerability Index (single-family)	#	%
Low	372	39.4
Moderate	167	17.7
Moderately-High	309	32.7
High	97	10.3
Total	945	100.0

Table 4.4 Wind Vulnerability Index (Single Family)

The wind vulnerability data does not display any distinct spatial relationships[8] indicating that vulnerability to high wind is dispersed throughout the island. However, when structures in urbanized areas was closely analyzed, data indicated that the majority of structures in Clark and Extension Clark are in the low to moderate vulnerability categories, while structures in the La Romana community show primarily moderate to high vulnerability. This may reflect the conversion from wood to concrete homes in the older communities such as Clark and more recent wood construction in La Romana. The analysis showed that only a few structures in Dewey are vulnerable to wind. Analysis also showed that houses along the coast in Barrio Playa Sardinas II are vulnerable to wind. Houses in Barrio Fraile showed all levels of risk according to their location in mountainous areas.

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[8] The Wind Vulnerability Structure Identification map illustrates classifications for all surveyed structures for moderate-high and high vulnerability.

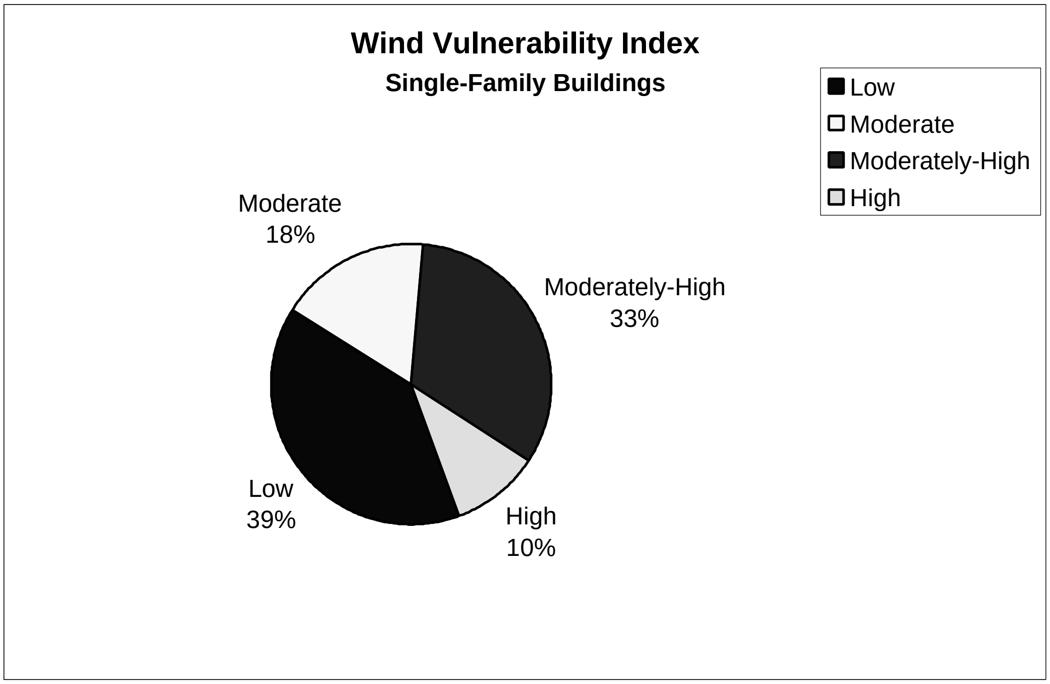

Figure 4.4 Wind Vulnerability Index (Single Family)

Wind Vulnerability Index (single family homes less than 600 sqf)	#	%
Low	106	35.1
Moderate	56	18.5
Moderately-High	123	40.7
High	17	5.6
Total	302	100.0

Table 4.5 Wind Vulnerability Index (Single Family homes less than 600 sq. ft)

4.5 Vulnerability for Storm Surge

Vulnerability to storm surge was determined by analyzing the characteristics of the structures in coastal high hazard area. Construction techniques and materials were used to determine those that are more resistant to the impact of storm surge associated with hurricanes. A total of one hundred twenty-nine (129) structures, residential and commercial, are located in this hazard zone. Forty-eight (48) structures were found to be highly vulnerable, while sixty (60) structures were at moderately high risk. Only twenty-one (21) of these structures were evaluated as having low to moderate vulnerability to storm surge due to construction.

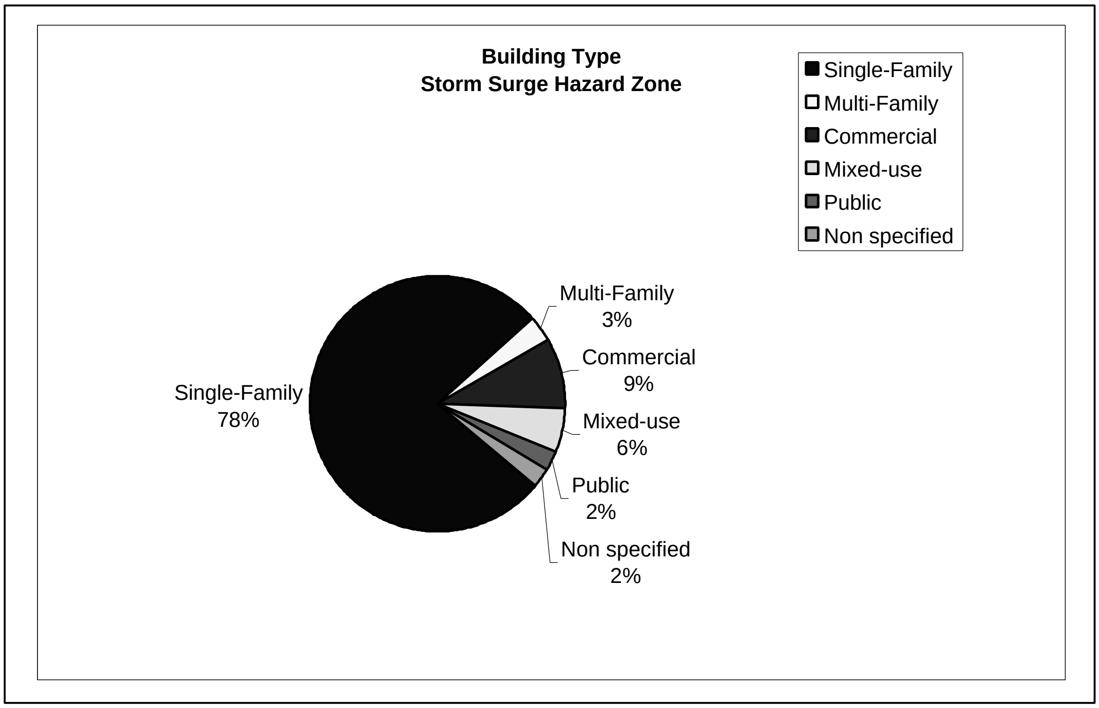

Figure 4. 5 Building Types in the Storm Surge

Of these structures, ninety-five (95) were identified as single-family homes. Within this subgroup, forty-one homes or 43% were built of concrete, seventeen (17) or 18% have a combination of concrete and wood with other materials and twenty-nine (29) or 31 % of homes were wooden structures.[9]

Surge Single Family Floor/Wall First floor	#	%
Wood/Other	29	30.5
Wood/Concrete	1	1.1
Concrete/Other	16	16.8
Concrete/Concrete	41	43.2
Not speciified	8	8.4
Total	95	100.0

Table 4. 6 Storm Surge Single family Dwellings Floor/ Wall combination (First Floor)

Distance from the shoreline was determined to be a key factor in this analysis. Out of the single-family home sub-group, seventy-four (74) or 75% were located less than 50 feet from shoreline making them highly susceptible to storm surge damages. Furthermore, none of these structures appeared to be higher than four (4) feet above sea level.[10]

Surge Distance for Shore Single Family Feet	#	%
10 or less	31	32.6
10 - 20	23	24.2
20 - 50	18	18.9
50 - 100	18	18.9
100 or more	5	5.3
Total	95	100.0

Table 4.7 Surge Distance from the shore

[9] Eight (8) structures were not evaluated in this field

10 The reader should note that distances from the shore and height of the first floor above sea level are approximate and should be considered estimates for the purpose of the ranking methodology. Actual or surveyed distances may differ significantly from field estimates.

Surge Height above sea level Single Family Feet	#	%
1	21	22.1
2	44	46.3
3	25	26.3
4	5	5.3
Total	95	100.0

Table 4. 8 Height of Single-family homes above Sea Level

4.6 Vulnerability for Flood Hazard

To determine the vulnerability of flood hazard a combination of criteria besides location were analyzed. These factors included height of the first floor from the ground surface and type of construction material for the first floor (wood or concrete).

Out of forty-one buildings identified within the 100-year flood hazard area, thirty-three (33) or 80.5% of these were identified as single-family homes. Only one public building, one multi-family structure, two commercial buildings and three buildings identified as mixed use complete this group.

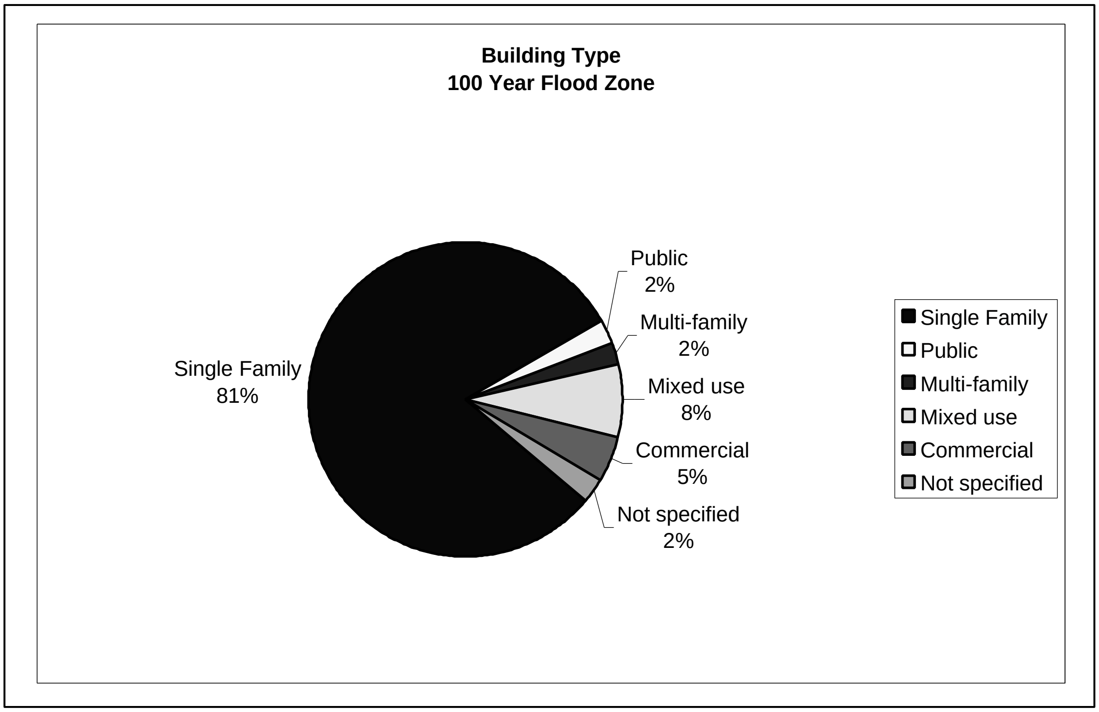

Figure 4. 6 Building Type 100 Year Flood Zone

Quality of construction within the group of houses varies. Nineteen (19) out of thirty-three (33) are considered to be of good or very good construction. Twelve (12) of these have raised first floors, and nineteen (19) are built slab on grade.

Quality of Construction	100 Year Flood Zone	
Single Family	#	%
Poor	5	15.2
Low	1	3.0
Fair	5	15.2
Good	13	39.4
Very good	6	18.2
Not specified	3	9.1
Total	33	100.0

Table 4. 9. Quality of Construction in 100-Year Flood Zone

These factors were combined and structures were ranked or given values for their susceptibility to flood hazards. Higher values indicate structures that are more vulnerable to flooding. Values 1, 2 and 3 account for eight houses and values 4, 5 and 6 account for twenty-five (25) houses.

Vulnerability Index	100 Year Flood Zone	
Single Family		
Value	#	%
1	1	3.0
2	5	15.2
3	2	6.1
4	3	9.1
5	18	54.5
6	4	12.1
Total	33	100.0

Table 4. 10. Vulnerability Index 100-Year Flood Zone

4.7 Summary: Vulnerability Analysis

The vulnerability analysis was driven by public input gathered during community meetings that placed the priority for implementing mitigation measures on strengthening the resistance of the housing sector to high wind damages from hurricanes.

Vulnerability for wind is strongly related to construction materials, height and location of the structure. Summary data for construction materials shows that 44% of one-story, single-family houses (675) are constructed of concrete walls and concrete roof; 43% have wood walls and wood roof, and 12 % have concrete walls with other materials for roof.

Sixty-one percent (61%) of all structures identified as two story homes have second floors built completely of wood. Twenty-two percent (22%) have concrete walls and concrete roofs, while seventeen percent (17%) have concrete walls with roofs of different materials. Only fourteen (14) three-story buildings were identified as residential units. Of these three-story buildings, seven (7) have wood walls and wood roof and seven (7) are in built in concrete or a combination concrete with other materials.

Two-story and three-story buildings are highly vulnerable to winds, particularly the units built completely in wood or those having concrete walls and wood roofs. Compiled data reflects that at least 116 houses in two and three story buildings fit into this description. These require further analysis in terms of structural engineering issues and quality of construction in order to determine retrofitting needs.

Homes with concrete walls and wood panel or wood metal roofs have to be evaluated differently. There are only about forty-three (43) structures that have concrete walls with non-concrete roofs that have been identified as having moderately high-to-high vulnerabilities for wind damages. These homes should be revisited in order to evaluate structural connections, presence of metal connectors or other mitigation measures. Assessments must take into consideration if the roofs are attached correctly to concrete beams and walls and if metal connectors have been appropriately installed to have the desired effect of keeping the roof in place in the advent of high winds.

Over time, concrete houses have proven to perform well under the impact of hurricane winds. There are about four hundred and forty-eight (448) structures (all types and heights included) built completely in concrete. For these structures, doors and windows should be assessed to see if they are securely attached to the building. Hurricane shutters are important preventative measure for such homes to avoid interior wind damages.

Homes constructed completely of wood (wood frame houses), if not constructed properly, can be highly vulnerable to wind damages. Approximately two hundred forty-eight (248) single-family, one-story structures are of wood frame construction. One hundred ninety-three (193) of these have fair, poor or low quality of construction and one hundred nineteen (119) of this group have an area of less than 600 square feet.

Moderately-High to High Vulnerability For All Structures	#	%
Construction Materials (One Story Building)		
Wall/Roof		
Wood/Non-Concrete	248	91.5
Concrete/Non-Concrete	23	8.5
Concrete/Concrete	0	0.0
Total	271	100.0
Construction Materials (Two Stories Building: Second Floor)		
Wall/Roof		
Wood/Non-Concrete	97	85.1
Concrete/Non-Concrete	17	14.9
Concrete/Concrete	0	0.0
Total	114	100.0
Construction Materials (Three Stories Building: Third Floor)		
Wall/Roof		
Wood/Non-Concrete	12	80.0
Concrete/Non-Concrete	3	20.0
Concrete/Concrete	0	0.0
Total	15	100.0

Table 4. 11 Moderately High-to-High Vulnerability of Structures on Culebra

Flood vulnerabilities are quite clear due primarily to location of structures either in the storm surge or 100 year flood zone. The only reasonable hazard mitigation measure that is appropriate for structures located within the storm surge storm is possible acquisition following a declared disaster utilizing FEMA Hazard Mitigation Grant Program (HMGP) funding. Structures located within the storm surge zone should not receive public retrofit funds for high wind damage mitigation. The rationale for this recommendation is that the public use of retrofit funds for increasing wind resistance should be targeted to lower hazard risk zones.

The type of hazard mitigation measure that would be most appropriate for homes located within the 100-year floodplain is floodproofing. The type of flooding expected in the 100-year floodplain is not riverine flooding with high velocity flows and would involve a slow rise and fall of the floodwaters. Both dry and wet floodproofing techniques would be appropriate in these conditions.

The vulnerability analysis presented here provides the next logical step for prioritizing hazard mitigation initiatives. It allows the Project Impact Committee to focus only on those structures that are highly vulnerable and maximize limited funds for mitigation retrofits. The Project Impact Committee should take into consideration the minimum level of structural integrity of a building necessary for an effective retrofit. For some poorly constructed structures, no amount of mitigation funds will make the structure disaster resistant. Implementing hazard mitigation retrofits for specific structures may require a more detailed structural assessment that address the quality of construction and provide engineering estimates for reconstruction. Detailed cost estimates will be necessary to determine what levels of assistance are economically feasible to strengthen specific buildings.

5 SUSTAINING PROJECT IMPACT CULEBRA

The Federal Government offers a wide range of funding and technical assistance programs to help make communities more sustainable and livable. Many of these are included in the technical assistance and funding matrix below. Programs have been identified with potential effectiveness in the construction or reconstruction of housing and businesses, public infrastructure (transportation, utilities, water, and sewer), and supporting overall hazard mitigation and community planning activities. Applications of these funds are emphasized in the matrix.

Grant Name	Agency	Sustainability and Hazard Mitigation Application	Contact
Housing			
Community Block Grant Program	Department of Housing and Urban Development (HUD)	Community development activities that meet long-term needs. These activities can include acquisition, relocation, reconstruction of properties and facilities damaged by a disaster and redevelopment of disaster affected areas	State and Small Cities Division, Office of Block Grant Assistance, CPD, HUD, 451 7th Street, SW. Washington, DC 20410-7000. 202-708-3587
Economic Development and Adjustment Program, Sudden and Severe Economic Dislocation (Title IX)	Department of Commerce, Economic Development Administration (EDA)	Project grants can be funded in response to natural disasters including improvement and reconstruction of public facilities	Disaster Recovery Coordinator, Economic Adjustment Division, EDA, DOC, Herbert Hoover Building, Washington, D.C. 20472 202-482-1222 or 800-482-6225
Hazard Mitigation Grant Program (HMGP)	Federal Emergency Management Agency (FEMA)	Project Grants can be funded for such activities as acquisition, relocation, elevation and improvements to facilities and properties to withstand future disasters	Director, Program Implementation Division, Mitigation Directorate FEMA, 500 C Street, SW, Washington, D.C. 20472 202-646-4621
Center for Excellence for Sustainable Development	Department of Energy (DOE)	Provides Technical assistance to disaster-affected communities as they plan for long-term recovery by introducing a wide-range of environmental technologies and sustainable redevelopment planning practices	DOE, Office of Energy, Efficiency and Renewable Energy, Denver Regional Support Office, 1617 Cole Blvd, Golden CO 80401 800-363-3732
Infrastructure			
Disaster Housing Program	Federal Emergency Management Agency (FEMA)	Program assistance may include 1.) Short-term lodging 2.) Home repair Assistance to restore the home to a livable condition; 3.) Rental Assistance; 4.) Mortgage and Rental Assistance; 5.) Small minimization grants to incorporate hazard mitigation into home repair	Human Services Division, Response and Recovery Directorate, FEMA, 500 C Street, SW, Washington, D.C. 20472 202-646-3632
Flood Control Works/Emergency Rehabilitation	Department of Defense, U.S. Army Corps of Engineers (USACE)	The Corps provides public works and engineering support to supplement state and local efforts towards the effective and immediate response to a natural disaster	Commander, USACE, Attn: CECW-OE, DOD, Washington, D.C. 20314 202-761-0251
Public Assistance Program	Federal Emergency Management Agency (FEMA)	These grants allow states and local units of government to respond to disasters, to recover from their impact and mitigate impact from future disasters	Infrastructure Support Division, Response and Recovery Directorate, FEMA, 500 C Street, SW, Washington, D.C. 20472 202-646-3026
Water Pollution Control	Environmental Protection Agency, Office of Water	Protecting the quality of ground and surface water	Office of Wastewater Management, Office of Water, EPA, Washington, DC 20460 202-260-6742
Water and Waste Disposal Loans and Grants	Department of Agriculture, rural Utilities Service	Use of energy efficient pumps and incorporate hazard mitigation measures when restoring or replacing damaged water and sewage systems	Assistant Administrator, Water and Waste, RUS, USDA, Washington, D.C. 20250-3200 202-690-2670

Historic Preservation			
Repair and Restoration of Disaster Damaged Historic Properties	Federal Emergency Management Agency (FEMA)	Preservation of historic structures is an important link to our past. By providing assistance in mitigating future damages, historic structures can be saved for future generations	Infrastructure Support Division, Response and Recovery Directorate, FEMA 500 C Street, SW, Washington, DC 20472 202-646-3026
Historical Preservation Fund Grants-in-aid	Department of the Interior, National Park Service (NPS)	Grants in Aid are provided for the identification, evaluation, and protection of historic properties by such means as survey, planning, technical assistance, acquisition, development, and certain tax incentives available for historic properties	Associate Director, Cultural Resources, NPS, DOI Washington DC 20240 202-343-9509
Land Management			
Emergency Watershed Protection	Department of Agriculture, Natural Resource Conservation Services	In preventing substantial run-off and erosion, the program helps prevent the future property loss and preserves soil resources	Deputy Chief for natural Resource Programs, NRCS, USDA, PO Box 2890, Washington, D.C. 20013 202-720-3527
Coastal Zone Management Administration Awards	Department of Commerce, National Oceanic and Atmospheric Administration (NOAA)	The program aids in the protection and preservation of sensitive coastal zones and provides the added benefit of reducing development in high coastal hazard areas	Chief, Coastal Programs Division, Office of Ocean and Coastal Resource Management, National Ocean Service, NOAA, DOC, 1305 East West Highway, Silver Spring Maryland 20910 301-713-3102
Coastal Wetlands Planning Protection and Restoration Act	Department of Interior, S Fish and wildlife Service (USF&WS)	The program aids in the protection and preservation of sensitive coastal areas	FWS, DOI Washington, DC 20240 703-358-2156
Land and Water Conservation Fund Grants	Department of Interior, National Park Service (NPS)	Project grants may be used for a wide range of outdoor recreation projects, such as picnic areas, campground, and boat launching areas, bike trails and support facilities.	Chief, Recreation Grants Division, NPS, DOI, PO Box 37127, Washington DC 20013-7127 202-343-3700
Disaster Specific Programs			
Park and Recreation Recovery Program	Department of Interior, National Park Service (NPS)	The program allows jurisdiction to provide recreational facilities in areas prone to natural disasters	Chief, Recreation Grants Division, NPS, DOI, PO Box 37127, Washington DC 20013-7127 202-343-3700
River Basin Program	Department of Agriculture, Natural Resource Conservation Services	Priority is given to projects designed to solve problems of upstream rural community flooding, water quality improvement that comes from agricultural nonpoint sources, wetland preservation, and drought management for agricultural and rural communities	Deputy Chief for natural Resource Programs, NRCS, USDA, PO Box 2890, Washington, D.C. 20013 202-720-3527
Watershed Protection and Flood Prevention	Department of Agriculture, Natural Resource Conservation Services	Protecting watersheds enable future generations to enjoy those watershed land resources in the future	Deputy Chief for natural Resource Programs, NRCS, USDA, PO Box 2890, Washington, D.C. 20013 202-720-3527
Earthquake and Hazard Reduction Grants	Federal Emergency Management Agency (FEMA)	Funds can be directed to help educate and protect individuals and property to the dangers of earthquakes	Director of Program Implementation Division Mitigation Directorate, FEMA 500 C Street, SW Washington, DC 20472 202-646-4621
Hurricane Program	Federal Emergency Management Agency (FEMA)	Funds may be used to establish enhance, and maintain basic levels of preparedness and mitigation capabilities. Also, funds can be used to conduct hazard identification and evaluation studies, and promote public awareness	Director of Program Implementation Division Mitigation Directorate, FEMA 500 C Street, SW Washington, DC 20472 202-646-4621
Flood Mitigation Assistance Program	Federal Emergency Management Agency (FEMA)	The program provides planning and project grants for projects that include mitigation activities that are technically feasible	Director of Program Implementation Division Mitigation Directorate, FEMA 500 C Street, SW Washington, DC 20472 202-646-4621

6 SUMMARY

In the year 2000, the Municipality of Culebra stands at a crossroads. All of the major infrastructure impediments to future growth has either been resolved or are in the process of being resolved. A reliable source and distribution system is in place for public water and for electric power. A new wastewater collection and treatment plant has been funded, designed and will be soon under construction. Will the future development on the island be more or less at risk from hurricanes and other natural disasters? Will families be living in locations outside of high-hazard zones and in structures that will withstand winds and other forces of nature? It is the hope of the authors of this multi-hazard risk and vulnerability assessment that the Project Impact Committee and the municipal government utilize the findings of this study to work towards a more sustainable future for the island.

Five major planning recommendations resulted from the multi-hazard risk assessment, as reflected in the Proposed Land Use Plan map, providing a foundation for a more sustainable future (see Section 3.6). These recommendations were incorporated into an Alternative Zoning Map that attempts to balance the need for future economic development with the need to limit development in areas of high composite risk and to maintain the tourism base of the local economy by preserving high value natural resource areas (Appendix 3). The Project Team recommends that the Project Impact Committee and concerned residents of the island use the political process to influence the Municipal Assembly not to adopt the Territorial Plan, in its current form. Section 3.7 provides recommendations for alternative zoning regulations that will ensure a more sustainable future for Culebra.

Many recommendations can be found throughout this study regarding individual hazard risks and appropriate mitigation measures for hazard risk reduction. Specific recommendations on floodplain management, landslides, high wind, and seismic hazards are briefly described in Sections 3.1.1 through 3.4.1 respectively.

The vulnerability analysis suggests measures that the Project Impact Committee and residents of Culebra can take to implement hazard reduction efforts for the existing structures on the island. Implementing wind hazard retrofit measures for single-family homes received the highest priority in the analysis. In addition to the series of vulnerability maps included in the Appendices, the Project Team will provide the Project Impact Committee with a list of single-family residences, identified by a sector map code, ordered from high to moderate vulnerability and in order of small to large structures. This ranking methodology will ensure that limited public funds reach those least able to afford them and ensure that limited resources reach the most families.

APPENDIX 1 DATABASE TABLE AND ATTRIBUTES (FIELDS)

The table lists all of the attributes compiled in the database and identifies those specific attributes (by **X**) that were used in the vulnerability analysis for each specific hazard.

No	Database Field Description	Database Field Name	Data Type	Wind	Surge	Flood	Comments
1	Structure Identification	Strid	Text (7)	X	X	X	
2	Inspector	Inspec	Text (50)				
3	Month	Month	Text (3)				
4	Day	Day	Text (2)				
5	Year	Year	Text (4)				
6	Address_1	Address_1	Text (50)				
7	Sub Division	Sub-division	Text (50)				
8	Building Type	Build_type	Text (15)	X	X	X	
9	Building Type Description	Build_ty_desc	Memo (Open)	X	X	X	
10.	Hieght	Height	Text (5)	X	X		
11.	Age	Age	Text (16)				Less than 1 1-5 Years 6-10 Years 11-20 Years Over 20 years
12.	Age Other Specify	Age_other	Number				Specify
13.	Size of Structure (square foot)	Size	Text (20)	X			Less than 600 sq. ft. 600-1000 sq. ft. 1000-1500 sq. ft. 1500-2000 sq.ft. Other
14.	Quality of Construction	q_const	Text (10)	X	X	X	Poor Low Fair Good Very good
15.	Building Construction	Build_const	Text (20)	X	X	X	Slab on Grade Raised first floor
16.	Raised Height of Substructure	Raised_height	Number	X		X	Height of substructure
17.	Number of Floors	Floors	Number	X	X	X	
18.	Substructure	Substruc	Text (16)	X	X	X	Concrete footing Wood piling Concrete piling Block piling
19.	Roof Frame	Roof_fram	Text (15)	X			Concrete Wood/panel Metal on wood
20.	Roof Cover	Roof_cover	Text (16)	X			Concrete Wood/panel Metal on wood Built-up
21.	Roof Pitch	Roof_pitch	Text (6)	X			Flat Steep Medium
22.	Coastal Area	Coastal	Yes/No		X	X	
23.	Height above water Line	H_above_w	Text (20)		X	X	1foot 2-5ft. 5-10 ft. 10-20 ft.

No	Database Field Description	Database Field Name	Data Type	Wind	Surge	Flood	Comments
24.	Distance from Shore	D_from _shore	Text (10)		X	X	Less than 10ft. Greater than 20ft. Greater than 50ft. Greater than 100ft. Greater than 150ft.
25.	Riverene Flooding	Riverine	Yes/No			X	
26.	Hazard from Gut	Ha_from_g	Yes/No			X	
27.	Height from Gut	H_from_g	Text (6)			X	Less than 2ft. Greater than 5ft. Greater than 10ft.
28.	Distance from Gut	D_from_g	Text (6)			X	Less than 5ft. Greater than 10ft. Greater than 15ft. Greater than 20ft.
29.	Window material	Window_mat	Text (6)	X			Glass Metal Wood
30.	Window Sizes	Window_size	Text (6)	X			3ft. x 5ft. 5ft. x 5ft. 6ft. x 5ft. Greater than 7ft X 5ft.
31.	Shutters	Shutter	Yes/No	X			
32.	Roof Height	Roof_height	Text (15)	X			Less than 30 ft. Over 30 ft.
33.	Roof Overhang	Roof_over	Text (10)	X			No 0 to 18" inches Over 18"inches
34.	Will topography effect wind velocity	Topo_effect	Text (3)				
35.	Roof Mounted Equipment	Roof_equip	Yes/No				
36.	Roof Mounted Equipment Description	Roof_equip_des	Memo				
37.	Previous Damages	Prev_damages	Yes/No				
38.	Previous Damages Description	Prev_dama_des	Memo				
39.	Type of use	Use	Text (50)				Police Fire School Manufacturing Other
40.	Doors	Doors	Text (5)				Small Large
41.	Type of Doors	Doors_type	Text (200				Wood Metal Glass
42.	Shelter	Shelter	Yes/No				
43.	Utilities Vulnerability	Utilities_vuln	Yes/No				
44.	Does Structure Require more study	More_study	Yes/No				
45.	General Comments	Comments	Memo				
46.	Mapping Internal Identification	Mapinfo_id	AutoNumber				
47	Building Type	B_type	Text	X	X	X	Single-family Multi-family, Commercial Public Mixed-Use
48	Identification	ID	Autonumber				
49	Structure Identification	strid	Text (7)				
50	Floor Type	Floor_type	Text (15)	X	X	X	Wood or Concrete
60	Number of Floor	Floor_num	Number	X	X	X	
61	Wall Type	Wall_type	Text (15)	X	X	X	

APPENDIX 2 HAZARD MAPS

- Digital Elevation Model
- Slope
- Landslide Susceptibility
- Soil Map (Types)
- Soils Suitability (Constraints)
- FEMA Flood Zones
- Tsunami Risk Levels
- Geology Map
- Wind Hazard Model
- Composite Risk Map

APPENDIX 3 PROPOSED LAND USE AND ZONING MAPS

- Proposed Land Use
- Proposed Zoning Map

APPENDIX 4 VULNERABILITY MAPS

- Vulnerability Tables
- Structure Identification Maps